Session IX No. 2

Modeling of Commercial Buildings for Optimal Regional Energy Conservation

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ABSTRACT

The Pacific Northwest Electric Power Planning and Conservation Act mandates the preparation of a regional power plan that identifies conservation and generation resources required to meet forecasted electrical demand in the region. To support the selection of appropriate resources for future development, the Northwest Power Planning Council sponsored a preliminary assessment of conservation and supply resources in the Pacific Northwest. This study concentrates on the commercial sector assessing the energy-saving potential of energy conservation measures (ECMs) at an electrical cost-effectiveness of 150 mils/kWh by the year 2000. The evaluation procedure involves: (1) establishing building prototypes, (2) establishing applicable energy-conservation measures and their resultant implementation costs, and (3) evaluating potential energy savings. The measures are prioritized into a cost-effectiveness curve, and a supply function is established relating building stock, ECMs' saturation and cost, ultimately determining the cost effectiveness of conservation and generating resources. Since this paper is based on a report available from the Northwest Power Planning Council in Portland, OR entitled Assessment of Electric Power Conservation and Supply Resources in the Pacific Northwest, the numerous references and detailed appendices are not cited here.

INTRODUCTION

This paper summarizes research conducted for the Pacific Northwest Electric Power and Conservation Planning Council with respect to electrical energy-savings potential in commercial buildings of the Pacific Northwest region. The research effort has three major purposes: (1) to provide a general overview of energy-use characteristics of commercial buildings, (2) to identify and assess the cost and effectiveness of practicable electrical energy conservation measures, and (3) to supply estimates of the aggregate reduction in electrical consumption of regional commercial buildings that may result through 100% adoption of the measures evaluated.

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The commercial buildings sector presents great opportunities and challenges for energy conservation. Commercial buildings consumed approximately 25 million megawatt-hours in 1980, nearly 17% of total Bonneville Power Administration power allocations. For the period from 1960 to 1978, the average annual rate of growth of electric-energy demand in the commercial sector was 7.65% while total sales grew at a rate of only 5.84%. Consequently, the commercial sector constitutes a growing proportion of total BPA power requirements. For perspective, the energy consumed in commercial buildings in 1980 is approximately equivalent to 2800 average megawatts.

Two basic types of energy-conservation measures in buildings are possible: those that reduce the supply of services such as heating, cooling, and lighting (reduction in amenity) and those that provide an equivalent level of service through the use of more efficient methods (end use efficiency improvement). This effort is focused on measures of the second category; only those measures that offer energy savings through more efficient use without significant change in the quality or quantity of services provided by energy-using systems are considered. Thus, except for the typically higher capital cost of energy efficiency and the lower energy consumption, the measures otherwise have negligible effect on the building.

The analytical efforts have been concentrated on a set of six building prototypes and approximately 15 generic energy-conservation techniques. Clearly, a multitude of other sets of building characteristics and conservation measures may arguably have benefits and drawbacks; however, for this pioneering effort, selection of prototypes and conservation measures for analysis is based predominantly on the professional judgment of Battelle and its prime subcontractor, Skidmore, Owings & Merrill of Portland, OR. As additional efforts are conducted and better information becomes available (indeed, even as a result of this analysis), improved selection and specification will be possible.

Two sets of building characteristic base cases were configured--one constructed prior to 1974 (pre-oil embargo); the other subsequent to 1974, when much greater emphasis on energy efficiency in buildings is evidenced. After compilation and review of a comprehensive list of energy-conservation measures, a set of approximately 15 measures having greatest likely applicability and cost-effectiveness were developed for parametric analysis of the prototypes.

More elaborate systems such as heat-recovery, thermal energy storage, cogeneration, earth sheltering, active and passive solar, and daylighting have not been assessed because of their typically higher costs or their relatively large impact on the configuration of the building structure and energy-use systems. In particular instances where conditions are right, such conservation measures have tremendous potential. However, for purposes of this initial effort they could not be adequately addressed.

The DOE 2.1A building energy-analysis program was used to develop estimates of the energy savings associated with most of the conservation measures. A complete set of parametric runs was made using weather data for Portland, OR, and a limited set of calibration runs was made using Tri-Cities, WA and Great Falls, MT weather data to determine percentage variations in performance to be expected in other climate zones.

Using the costs and energy savings determined for the measures as applied to the various prototypes, and the limited information available regarding the energy use characteristics of the regional buildings stock, estimates were prepared aggregating energy savings and costs. This information takes the form of supply functions that relate the amount of potential energy savings in commercial buildings to the levelized costs (mils/kWh) of conserved energy.

DOE 2.1A was selected for this effort based upon its use in the Building Energy Performance Standards project and the California Energy Commission activities. An hourly simulation tool was considered necessary to properly account for the complex interactions of conservation measures with overall building energy usage. A comparison of simulated results with those of other methods reveals that DOE 2.1 renders consistent results.

METHODOLOGY

The general approach used in identifying and estimating the cost and potential energy savings of building conservation measures was to:

1. Disaggregate energy use according to building type, climate region, end-use, ownership, and fuel type
2. Formulate prototypical building configurations representative of the region
3. Identify practicable energy-conservation measures and select a representative set for analysis
4. Estimate the current and projected costs of the conservation methods for the prototype buildings
5. Evaluate the energy-saving performance of prototype buildings measures in the various climate regions
6. Construct representative supply functions.

The use of prototypical buildings to provide estimates of the costs and performance of energy-saving measures has the advantage of explicit consideration of the interactional effects of conservation measures with one another. The major disadvantage of the approach is that the wide variety of commercial building configurations and energy use systems cannot be rigorously assessed with a workable number of prototypes.

Estimates of square footage and energy usage by major commercial sectors were prepared by the Bonneville Power Administration using the Oak Ridge Commercial Model. A large-scale effort to gather data on a sample of more than 1200 commercial buildings in Portland, OR and Seattle and Tri-Cities (Richland, Pasco, Kennewick) WA was conducted in 1979-1980 by Westat Inc. for BPA and the Energy Information Administration (EIA); however, no published data are yet available. A copy of the computerized data file (with square-footage data masked to prevent possible identification) was obtained and analyzed for this study to provide an indication of the levels of energy efficiency in the existing building stock. For future building characteristics, a data base called "Live Leads", having characteristics for 400 new commercial buildings, was reviewed. A report containing the findings of this assessment is to be published soon. From these sources, prototypical baseline characteristics and an estimate of the saturation levels of some energy-conservation measures were developed.

A comprehensive set of energy-conservation measures was assembled from a variety of sources and reviewed to identify a workable number of generic energy-conservation methods. For each of these selected methods, engineer cost estimates were developed, and estimates of energy savings were generated by parametric analysis using the DOE-2 building energy analysis program. Impacts on peak electrical requirements are noted as well.

For each measure, a levelized cost is determined for application to buildings with and without electric space heating. For all measures, a present-value cost for a 30-year economic life is calculated and used to calculate a levelized electricity cost. The present worth factor for a stream of energy savings over a 30-year period with a 3% real discount rate is 19.6. Thus, the levelized cost of conserved energy is calculated by the relation:

$$LC = \frac{CC\ (1000)}{(19.6)E}$$

where

LC = levelized cost, (mils/kWh)

CC = capital cost, (1980 $)

E = annual energy savings, (kWh)

Multiplying the energy-savings estimates by the square footage of buildings to which the measure can be applied, results in an estimate of aggregate energy savings in the region attributable to individual measures. Summing these values according to their levelized costs, a supply function is derived which relates the levels of cost effective conservation achievable over a range of energy supply costs.

To display the methodology, this paper highlights the analysis for the new large office prototype. The full report includes similar treatment for all the building sectors examined, as well as additional material on constraints to implementation and data-base development. Also included is additional information on the formulation of prototypical building characteristics. Basically professional judgment combined with a review of past and present building standards was used to develop representative building geometry and energy-use characteristics. One of the innovative aspects of this project is that no fuel costs need be assumed; the effective cost of conserved energy is derived from capital cost and performance data.

PROTOTYPE CHARACTERISTICS/GEOMETRY

Prototype buildings were developed for the following sectors:

1. Large offices
2. Small offices
3. Hotels
4. Motels
5. Non-food retail
6. Schools

The modeled prototypes were configured to represent buildings constructed according to generally accepted design practices of the day with minimal attention to energy-efficiency. This modeling required that "worst-case" conditions from an energy-efficiency standpoint be determined for both the new and existing building stock, so that a maximum number of practicable conservation measures could be examined subsequently.

Thermal envelope and equipment characteristics were developed for each building sector in two configurations--one corresponding to pre-1974 construction practices (OLD) and one corresponding to post-1974 practices (FUTURE/NEW). The year 1974 was selected as a breakpoint because of the significantly greater attention to energy efficiency following the oil embargo of 1973.

The usage and operation profiles of buildings are a major, if not paramount determinant of energy consumption. For this reason, it is important that the values assumed be reasonably representative of typical conditions. Standard building profiles were drawn from earlier efforts of this type for the U.S. Department of Energy and the California Energy Commission. These included profiles for occupancy, lighting, domestic hot water usage, elevators, fans, etc.

The performance of many building conservation measures also depends on climatic variables. Thus three climate zones were established, corresponding roughly to the combined number of heating and cooling degree-days:

	Combined Degree Days (65 F)	General Geographical Area
Zone 1	4000 to 6000	West of the Cascade Mountains
Zone 2	6001 to 8000	Between the Cascades and the western boundary of Idaho
Zone 3	8001 to 9000	East of the western Idaho boundary

Actual prototype buildings for each of the six commercial sectors were generated complete with floor plans, building construction specifications, equipment, and usage typical of practices followed under the pre-1974 (OLD) and post-1974 (FUTURE/NEW) eras. To simplify analysis the building dimensional data remained the same for each building type, and different envelope/equipment packages were tailored for each era. An illustration of the format used in this analysis for the large office prototype is presented in Fig. 1.

The remaining building prototypes are described here:

SMALL OFFICE BUILDING (Single Level, 20,045 ft^2 (1,860 m^2))

Old: R-5 (R-0.88) walls; 50% single clear glazing; R-5 (R-0.88) roof; 4.0 W/ft^2 (43 W/m^2) fluorescent lighting; packaged electric rooftop air conditioning unit.

New/Future: R-11 (R-1.93) walls; 35% double clear glazing; R-10 (R-1.76) roof; 3 W/ft^2 (32 W/m^2) fluorescent lighting; packaged rooftop heat pump unit.

HOTEL (22 Floors, 456 Guest Rooms, 294,000 ft^2 (27,310 m^2))

Old: R-3 (R-0.53) walls; 45% single clear glazing; R-9 (R-1.58) roof; 1.25 W/ft^2 (13.5 W/m^2) guest rooms incandescent lighting; 4.0 W/ft^2 (43 W/m^2) conference rooms fluorescent lighting; central 4-pipe fan coil system.

New/Future: R-10 (R-1.76) walls; 45% double clear glazing; R-9 (R-1.58) roof; 1.25 W/ft^2 (13.5 W/m^2) guest rooms incandescent lighting; 4.0 W/ft^2 (43 W/m^2) conference rooms fluorescent lighting; central 4-pipe fan coil system.

MOTEL (2 Floors, 119 Guest Rooms, 26,950 ft^2 (2,500 m^2))

Old: R-3 (R-0.53) walls; 15% single clear glazing; R-4 (R-0.70) roof; 1.25 W/ft^2 (13.5 W/m^2) incandescent lighting; unitary through-the-wall air conditioners with integral electric strip heat.

New/Future: R-7 (R-1.23) walls; 15% single clear glazing; R-10 (R-1.76) roof; 1.25 W/ft^2 (13.5 W/m^2) incandescent lighting; unitary through-the-wall heat pumps.

RETAIL (3 Floors, 120,000 ft^2 (11,150 m^2))

Old: R-3 (R-0.53) walls; 10% single clear glazing; R-9 (R-1.58) roof; 6.0 W/ft^2 (64.5 W/m^2) at 70% fluorescent/30% incandescent lighting; rooftop electric constant volume multizone with dry bulb economizer.

New: R-8 (R-1.41) walls; 10% single clear glazing; R-9 (R-1.58) roof; 6.0 W/ft^2 (64.5 W/m^2) at 70% fluorescent/30% incandescent lighting; single duct variable air volume air system with enthalpy economizer and centrifugal chiller/cooling tower.

SCHOOLS

Old: 67,230 ft^2 (6,245 m^2), single level; R-3 (R-0.53) walls, 50% single clear glazing; R-10 (R-1.76) roof; 3.5 W/ft^2 (32.2 W/m^2) incandescent lighting; low pressure steam unit ventilators.

New: 43,000 ft^2 (3,995 m^2), single level; R-9 (R-1.58) walls; 40% single clear glazing; R-10 (R-1.76) roof; 2 W/ft^2 (21.5 W/m^2) fluorescent lamps; packaged electric rooftop air conditioning unit.

ENERGY CONSERVATION MEASURES (ECM) CATEGORIES

A large number of practicable electrical energy-conservation measures can be applied to the wide variety of commercial building types considered in this assessment. Since it would not be possible to evaluate all of them in this preliminary effort, initial efforts focused upon developing a complete listing of candidate measures. These energy-conservation measures have been grouped into five categories:

1. Operational--alteration of how the building is operated and maintained with no major cost expenditure (for example, opening windows for cooling, setting back thermostats at night and replacing filters).
2. Siting--alteration of the orientation or surrounding of the structure to save energy through solar access, wind protection and earth sheltering.

3. Envelope--modification to the thermal characteristics of the building shell through the addition of insulation, storm windows or various infiltration control devices.
4. Equipment--improvements in the system efficiency of energy consuming equipment and appliances such as furnaces, air conditioners and water heaters.
5. Renewables--provision to use renewable resources such as wood and solar as a substitute for electricity.

From this detailed listing of candidate ECMs, Fig. 2, a set of generic conservation measures was selected for analysis. The rationale used to select measures for analysis included the following considerations: (1) they represent the lowest-cost opportunities for conservation, (2) they utilize currently available and demonstrated technology, and (3) they be amenable to reasonably firm cost estimation and energy-performance evaluation.

The selected measures were:
--Deadband thermostats
--Reduction of outside air
--Night-low-limit controls
--Efficient lighting
--Envelope insulation
--Window glazings
--Economizer cycles
--Conversion to variable-air-volume systems
--Deck temperature reset controls
--Heat pumps

Emerging new technologies that show great promise for reducing energy use in commercial buildings were not assessed in detail because of their uncertain costs and performance on a case-by-case basis. The following techniques, however, appear to have potential for cost-effective application in the region:
--Air or water heat-recovery systems that transfer sensible and/or latent energy from exhaust to supply streams
--Energy storage systems which store hot and/or cold thermal energy to shift utility demands or match noncurrent energy requirements
--Natural lighting techniques that employ effective use of daylight to offset artificial lighting requirements
--Cogeneration of electrical and thermal energy at the building site to meet electrical and thermal energy requirements simultaneously
--Solar energy systems that can provide space heating and cooling and domestic water heating

ENERGY CONSERVATION MEASURE COSTS

For each ECM, a generic unit price was calculated incorporating factors for material, labor, contractors' overhead and profit, and maintenance/operating cost. The unit price was then applied to each of the retrofitted "OLD" or "NEW" models in addition to the "FUTURE" prototype, and total installed and operating/maintenance costs were calculated for each ECM measure.

Regional material and labor unit cost factor differences which range from 0.90 to 1.10 were not considered. These cost factors would be applicable, however, for a specific site evaluation. Additionally, insurance factors which generally range from 2 to 8% depending on the protection class, were evaluated at an average of $3/1000 or 0.3% factor per year.

A sample of the format used for a unit price cost is shown in Fig. 3. Conservation-measure costs were established by a review of various cost guides and actual job estimates from numerous regional vendors. Material and labor costs are estimated for each measure, and an overhead and profit of 15% is added to render better approximations of actual field costs. As mentioned earlier insurance factors of 0.3% per year are then uniformly applied.

ENERGY CONSERVATION MEASURE PERFORMANCE

This section discusses the methods employed and assumptions made to estimate the energy-saving performance of the selected conservation measures in the prototype buildings. The author's effort to use conservative assumptions to estimate energy savings from implementing particular measures has relied largely on the ability of a detailed building energy-analysis computer program to provide such estimates.

The analysis of energy-conservation measures consists of five major steps:

Step 1: Develop computer input files of the base-case prototypes

Step 2: Calibrate base-case energy consumption against available data and energy-use information

Step 3: Apply conservation measures to prototypes by reconfiguring computer input files and tabulating output results

Step 4: Develop engineering estimates of energy-conservation measure costs

Step 5: Calculate cost per unit of energy savings of conservation measures.

Most estimates of the energy savings resulting from implementation of energy-conservation measures in the prototypes are derived from the results of computer simulation. The DOE-2.1A building energy-analysis program, developed by researchers at Lawrence Berkeley and Los Alamos National Laboratories, has been selected as the primary evaluation tool for this effort. Comparisons of the simulated results of DOE-2 with other available building energy analysis tools has indicated that the results are consistent and close to the average. Although all of the programs as yet have limited validation against actual commercial building energy usage, they are considered to be reliable indicators of relative variations of performance.

Because of the complexity and uncertainties surrounding specification of hypothetical building configurations, the input files must be carefully reviewed to verify simulation accuracy. This is imperative to assure reasonable results. Time and budget limitations have precluded a complete line-by-line verification of simulated results.

Data concerning the actual energy consumption of commercial buildings, particularly information on building and occupancy characteristics, are limited. Such data are often considered proprietary by commercial building owners and utilities, and the data available are commonly not at a level of disaggregation to be useful for calibration of computer simulations. Consequently, the major source of information on commercial building energy consumption by end use has its basis in computer simulation and professional judgment.

Input files are altered to evaluate the performance of the prototype buildings with the conservation measure in question. The measures are added sequentially, such that the prototype performance is continually improved. Resultant impacts on energy for heating, cooling, HVAC auxiliaries (largely ventilation), hot water, lights, vertical transportation, and miscellaneous are compared and tabulated. Peak electrical demand is also presented.

A full set of runs has been made for all-electric commercial buildings using Portland, OR weather data. Climatic influences on the performance of conservation measures in buildings are handled through the use of climate multipliers. For buildings with non-electric heat, performance is estimated by subtracting the energy used for space heating from the total and calculating incremental impacts that occur with respect to the other electrical end uses.

Two tables have been prepared for each set of parametric runs to summarize the results. The first table in the set, "Conservation Measure Cost-Effectiveness," lists the run number and description, followed by the capital cost of the measure as applied to the prototype. The capital costs and incremental affects of the measure on total energy and peak demand requirements per 1000 ft^2 (92.9 m^2) of gross floor area are presented next. From this data the levelized cost for conserved energy and capacity reductions is calculated. The final three columns present the percentage of the building that has the measure installed, the remaining electricity consumption in kilowatt-hours per 1000 ft^2 and the peak capacity requirement in kilowatts per 1000 ft^2.

The second table of the set, "Conservation Measure Annual Energy Impacts," presents a disaggregate of the impact of the conservation measure on major end-use categories. The final column, "Nonelectric Heat" gives the difference between the total and the heat columns and is used to derive the entries listed in the preceding table under "Without Electric Heat."

The following listing briefly describes the energy conservation measures for which computer simulations were conducted. The measures are listed in the order they were cumulatively applied to the base prototypes. Ideally, these would be ordered according to their calculated levelized costs; however, the analytical burden of the repeated simulations necessary to facilitate such ordering is beyond the capability of this initial effort.

Eleven parametric runs were made for the new office prototype:

1. Energy-intensive base case
2. Outside air reduced from 20% to 10% of supply air
3. Lighting reduced from 2.0 to 1.75 w/ft^3
4. Lights scheduled such that 90% of installed capacity is used from 7:00 a.m. to 5:00 p.m., and 5% during all other hours
5. Escalator scheduled to be operating only from 7:00-10:00 a.m. and 4:00-7:00 p.m.

6. Reflective window with .25 shading coefficient installed in lieu of tinted glazing with shading coefficient of .55
7. Wall insulation altered from R-5 to R-11 and ceiling insulation from R-8 to R-19
8. Wall insulation altered from R-11 to R-19 and ceiling insulation from R-19 to R-30
9. Double-pane windows altered to triple pane
10. Deck-temperature reset capability installed
11. Optimal start controller installed, which effectively allows setback temperature to be maintained an average of 2 hours longer.

The results of these runs are presented in Figures 4 and 5.

CONSERVATION SUPPLY FUNCTION

A supply function is a convenient way of depicting the relationship between the costs and effectiveness of practicable energy-conservation techniques. If it is assumed that the levelized costs and energy savings derived from the prototype building analysis are representative and, therefore, generally applicable to the regional building stock, an aggregate supply function can be developed by estimating the technically achievable levels of saturation and square footage of buildings affected. The validity of this approach rests largely upon how representative of the prototype buildings and conservation measures applied are.

Four major steps are required to convert the levelized cost and energy-savings data of Fig. 5 into supply functions. First, the percentage of building square footage to which the measures (or ones of similar cost-effectiveness) can be applied is estimated. Then, using data regarding the existing forecast quantity of building square footage of that type, the aggregate applicable square footage is calculated. Since information regarding the distribution of building characteristics among climate zones is not known, a method of accounting for the affects of climate on the quantity of conservation available was developed. Finally, a series of key assumptions, which permit aggregate conservation supply to be calculated, are made.

To estimate the amount of energy savings that can result from full implementation of a particular measure, it is necessary to estimate what proportion of the building stock already has adopted the measure in question or is otherwise restricted from applying it. Factors restricting the application of conservation measures for use in estimating technically achievable levels of electrical savings include:

-- Pre-existence of the measure in question
-- Technical constraints to implementation, such as nonapplicability to particular HVAC system types
-- Usage of nonelectric energy sources.

Additional factors must be considered to estimate expected levels of penetration under various energy-cost scenarios and incentive programs; however, the estimates provided in this effort are of technical potential and assume saturation (100% penetration) of technically applicable conservation potential.

In practice, various technical constraints to the implementation of particular conservation measures may exist. Some HVAC or structural systems cannot accommodate certain types of conservation measures, and, in some cases, the interactions of various building systems may negate potential energy savings. Because of insufficient data to consider this affect in detail, only 50% of the floorspace estimates was used to generate the supply functions. This assumption is considered to be conservative to assure that conservation potential not be overestimated.

To calculate the applicable square footage of commercial buildings to which conservation can be applied, estimates of the total square footage of commercial buildings by sector are needed. The square-footage estimates developed by BPA for its April 1982 load forecast have been used here. Between 1980 and 2000, an additional 151 million square feet of large offices are estimated to be serviced by BPA and an additional 89 million square feet serviced by private utilities in the BPA service area.

In recognition of the fact that the energy-savings potential of most conservation measures is related to some degree to the intensity of climatic extremes and overall severity of the climate, a methodology was developed to estimate such effects. Because no data that reveals the distribution of commercial building square footage or characteristics by climate zone are available, running the full set of parametrics through each climate tape would not substantially improve the resulting supply functions.

As a proxy for the distribution of electrically and nonelectrically heated commercial buildings in the various climate zones, information on residential structures was applied. The rationale is that commercial building distribution is proportional to the distribution of households and that the share of electric heat is proportional to the share of electric heat in residences. The resultant distributions are presented in Tab. 1.

Next, the relative severity of the climate is considered by comparing the base-case runs for the new building prototypes (approximating the mean building characteristics) in each of the climate zones. Two ratios are computed for use in the development of multipliers. First, total energy requirements for zones 2 and 3 are divided by the zone-1 total for application to the all-electric buildings stock. The second multiplier is computed for nonelectrically heated buildings by substituting total energy less heating energy for the totals used before.

TABLE 1

Assumed Distribution of Commercial Buildings
(Percentage of Total Stock)

	Zone 1	Zone 2	Zone 3	All Zones
Electric Heat	25	18	5	48
Nonelectric Heat	27	14	11	52

Multiplying these computed "severity ratios" by the percentage of distribution data in Table 1 and summing yields, a multiplier that can be applied to the Zone 1 performance data and aggregate applicable square footage. This allows the magnitude of the calculated energy savings to reflect the relative severity of climates in the Pacific Northwest. Although the cost-effectiveness of the measures in each may vary, the effect on aggregate supply functions is small.

Ordering the conservation measures analyzed according to their levelized cost, with the lowest considered first, allows a supply function to be constructed. The applicable square footage, derived after accounting for the percentage of restrictions and the penetration of electric heat, is multiplied by the incremental energy savings and the climate multiplier derived earlier and is converted to average megawatts. The incremental cost of the measure is multiplied by the applicable square footage to derive an aggregate cost.

Accumulating the energy savings each step of the way permits a total energy savings potential to be calculated for valuing energy at that levelized cost. These energy-savings data at various levelized costs comprise the innputs to the supply function. The estimates of electrical conservation resource potential for large office buildings to be constructed by the year 2000 are presnted in Fig. 6. The run numbers correspond to options as listed in Fig. 5, with the "x" series corresponding to buildings with nonelectric heating. Incremental and cumulative ECM savings and costs, as well as the levelized costs calculated previously, are presented.

CONCLUSIONS AND RECOMMENDATIONS

This section presents observations regarding the sucess of the analysis, provides a summary of findings, and offers recommendations for further study. Because analytical efforts leading to the development of supply functions for all sectors have not been carried out, and review and calibration of the computer simulations is under way, the findings are preliminary. The efforts conducted to date, however, do indicate the general magnitude of potential energy savings and identify areas that would benefit most from additional study.

Findings

A review of the supply-function tables indicates that the majority of potential energy savings quantified is available to the region at very low cost, largely because of the low-cost HVAC system control improvements--which can have a large impact on energy requirements for heating, cooling, and ventilating. The true magnitude of such savings as applied to particular buildings will vary widely, so the magnitude of savings quantified from one simulation is of questionable validity. Nonetheless, since additional data is currently unavailable, the savings are assumed to be representative.

Aggregate supply functions for existing and new commercial buildings can be developed by accumulating data for the sectors analyzed. Figure 7 presents total levels of energy savings quantified to be cost-effective at levelized costs ranging from 1 to 150 mills/kWh. Judgment has yet to be applied to account for the sectors not evaluated with prototypical analysis, but perhaps twice these levels of energy savings are available in total.

For existing buildings, relatively large levels of energy savings are quantified for the large office and retail sectors, due to the energy intensity of the base cases in these subsectors and the large levels of aggregate floor space. If the energy usage of laundries, kitchens, and recreational facilities associated with hotels and motels is considered, considerably less disparity with energy savings in other sectors would be evidenced.

For new buildings, energy savings totalling 235 MW have been quantified for the period 1980 to 2000, based on improvements of new buildings using available and demonstrated technology. Large potential savings available from emerging technologies should be incorporated as documented performance data become available. Since only a portion of the total commercial sector has been considered, and some energy-consuming aspects of buildings analyzed are not included, perhaps twice this amount is available in the aggregate.

General Observations

This assessment of commercial energy-savings potential has exposed how little is really documented about the subject, how complex rigorous study based upon engineering principles becomes, and how high the potential magnitude of cost-effective levels of energy savings available to the region are. Nearly all the data utilized for this study had to be developed as work proceeded on concurrent tasks, thus creating some confusion and opportunity for error. Major subtasks of this effort, such as the prototype building development, the review of commercial buildings surveys, and conservation measure identification and costing, can stand alone to support subsequent efforts.

The supply functions depicted for large office buildings indicate the sensitivity of the analysis to the energy efficiency of the base case and the saturations of energy-conservation measures. The large difference between the future (1980-2000) energy-savings potential and that for the existing stock is predominantely due to the relative energy intensity of the existing office prototype. The great deal of uncertainty surrounding actual levels of energy usage for commercial buildings in the region may soon be resolved as utility data from the BPA/EIA Commercial Buildings Survey become available. In the absence of such data, calibration of the computer simulations is tenous.

Since the results of this analysis are, at this point, based on simulated rather than realized performance of energy-conservation measures, the level of confidence in the absolute levels of savings quantified is reduced. The strength of this approach is to identify and evaluate promising conservation measures in a variety of building types and examine their impacts on various end-use and peak-energy requirements. To improve confidence in the accuracy of these results, field testing combined with end use metering is required. In the absence of such hard scientific fact, continued analysis cannot provide conclusive findings.

The cost estimates here are based on rectifying energy inefficiencies once they are identified and, therefore, do not incude the cost of the energy audit likely to be necessary to specify them. Because of the individual nature of commercial buildings, a detailed assessment of conservation potential by a trained professional is an important first step to improve the efficiency of energy usage. Costs for such audits may vary from $5 hundred to $30 thousand, depending on the complexity and rigor of the effort. However, in most cases this fee will be rapidly repaid through reduced utility bills.

Recommendations for Further Study

The broad scope of this analysis, combined with the level of detail required for defensible estimates of energy savings, has forced limitations to be placed on consideration of practicable conservation measures. It is hoped that additional studies can focus on particular building subsectors and, building on this effort, significantly improve and extend the analysis. Such focus will allow quantifications of needed sensitivities of performance and costs of conservation measures within particular sensors.

Commercial building subsectors not analyzed here, but used in the revised Oak Ridge Commercial Model, should be subjected to prototypical analyses. Namely, the warehouse, hospital, grocery, and restaurant subsectors deserve detailed assessment. Efforts under way by Synergic Resources for BPA should soon be available to fill the void to some degree.

Application of emerging energy-conservation technologies not explicitly considered in the analysis should increase energy-conservation potential in future buildings significantly. Because this effort has focused on well-understood and widely demonstrated conservation techniques, which are incorporated into many new buildings, the estimate of future energy savings potential is conservative. Further analysis and documentation of the effectiveness of emerging energy-conservation measures is needed.

Documented information regarding the results of commercial building energy audits in the region would be invaluable in better characterizing the building stock and calibrating the computer simulations. A consistent reporting format for the findings of energy audits would facilitate this endeavor. Coordination among the various entities conducting audits is highly recommended, thereby allowing results to be mutually useful.

Field experience with electrical-energy-conserving strategies should be documented and compiled for review and analysis. A data base upon which to verify the accuracy of the results of computer simulation is needed. The data base would also be useful in the development of actual measure costs.

LARGE OFFICE BUILDING

PHYSICAL CHARACTERISTICS	FUTURE/NEW	OLD
Area	37,160 m^2 (400,050 FT^2)	37,160 m^2 (400,050 FT^2)
Number of Floors	20	20
Dimensions	45 m (150') lg. x 36.5 m (120') wide x 85.3 m (280') high	45 m (150') lg. x 36.5 m (120') wide x 85.3 m (280') high
Glass/Wall Ratio	35%	50%
Glass	Tower: Double tinted; U=3.17/2.78 (0.56/0.49) Summer/winter, SC=0.55 Lobby: Single Clear; U=5.90/6.41 (1.04/1.13) Summer/winter, SC=0.95 3.05 m (10'-0") height	Tower: Single clear; U=5.90/6.41 (1.04/1.13) Summer/winter, SC=0.95 Lobby: 3.05 m (10'-0") height
Walls	Precast 10 cm (4") concrete, 2.54 cm (1") airspace, 8 cm (4") stud wall, R-0.88 (R-5) insulation, R_T=1.41 (8), U_T=0.709 (0.125)	Precast 10 cm (4") concrete, 2.54 cm (1") airspace, 10 cm (4") stud wall, no insulation, R_T=0.52 (3), U_T=1.873 (0.33)
Underground Walls	15.2 cm (6") concrete, 5.08 cm (2") stud wall, R-0.53 (R-3) insulation, R_T=0.705 (4), U_T=1.41 (0.25)	15.2 cm (6") concrete, 5.08 cm (2") stud wall, no insulation R_T=0.176 (1), U_T=5.678 (1.0)
Roof	15.2 cm (6") concrete, R-1.41 (R-8) insulation, built-up roofing, R_T=1.59 (9), U_T=0.62 (0.11)	15.2 cm (6") concrete, R-1.41 (R-8) insulation, built-up roofing, R_T=1.59 (9), U_T=0.62 (0.11)
Floor	15.2 cm (6") concrete slab	15.2 cm (6") concrete slab
Ground Slab	15.2 cm (6") concrete slab, R-0.176 (R-5) polystyrene perimeter insulation to a depth of 0.61 m (2 feet)	15.2 cm (6") concrete slab, no perimeter insulation, R_T=0.08 (0.5), U_T=11.3 (2.0)
Floor-to-Floor Height	3.96 m (13'-0") Tower 4.42 m (14'-6") Basement, Ground 4.57 m (15'-0") Lobby 8.08 m (26'-6") Penthouse	3.96 m (13'-0") Tower 4.42 m (14'-6") Basement, Ground 4.57 m (15'-0") Lobby 8.08 m (26'-6") Penthouse
Ceiling Height	2.60 m (8'-6") Tower, Basement Ground 3.35 m (11'-0") Lobby	2.60 m (8'-6") Tower, Basement, Ground 3.35 m (11'-0") Lobby
LOAD SURFACE AREA SUMMARY		
A. Gross Glass (Double/Single) m^2 (FT^2)		
North	811/111 (8,735/1,200)	1,270 (13,680)
South	811/111 (8,735/1,200)	1,270 (13,680)
East	1,014/140 (10,920/1,500)	1,588 (17,100)
West	1,014/140 (10,920/1,500)	1,588 (17,100)
Total	3,650/502 (39,310/5,400)	5,716 (61,560)
B. Net Wall Including plenum exposure m^2 (FT^2)		
North	1,858 (20,005)	1,150 (16,260)
South	1,858 (20,005)	1,510 (16,260)
East	2,322 (25,005)	1,888 (20,325)
West	2,322 (25,005)	1,888 (20,325)
Total	8,360 (90,020)	6,800 (73,170)
C. Underground Wall m^2 (FT^2)	2,365 (25,460)	2,365 (25,460)
D. Roof m^2 (FT^2)	1,672 (18,000)	1,672 (18,000)
E. Floor Perimeter m (FT)	165 (540)	165 (540)
Infiltration Rate	2.03 x 10^{-4} m^3/sec - m^2 (0.04 CFM/FT^2) of wall area	2.03 x 10^{-4} m^3/sec - m^2 (0.04 CFM/FT^2) of wall area
Occupancy		
Density	13.9 m^2/person (150 FT^2/per.)	13.9 m^2/person (150 FT^2/per.)
Max. Capacity	2400	2400
Heat Load/Person	73/58 W (250/200) BTUH Sensible/latent	73/58 W (250/200) BTUH Sensible/latent

Figure 1. Characteristics of the large office prototype

LARGE OFFICE BUILDING

PHYSICAL CHARACTERISTICS	FUTURE/NEW	OLD
Lighting		
Type	3-tube fluorescent	4-tube fluorescent
Level	21.5 W/m^2 (2.0 W/FT^2)	43.0 W/m^2 (4.0 W/FT^2)
Lighting Zones	150	150
No. of Fixtures	6670	10,000
% to Return Air	30%	30%
Control Strategy	Time clock control	Local control
Appliance	5.4 W/m^2 (0.5 W/FT^2)	5.4 W/m^2 (0.5 W/FT^2)
Exterior Lighting	Mercury vapor @ 2.69 W/m^2 (0.25 W/FT^2)	Fluorescent @ 2.69 W/m^2 (0.25 W/FT^2)
Domestic Water Heating	Electric water heaters, recirculated system 49°C (120°F). 3.78 x 10^{-3} m^3/person-day (1.0 gal./person-day)	Electric water heaters, recirculated system 49°C (120°F). 3.78 x 10^{-3} m^3/person-day (1.0 gal./person-day)
Cooling System	Single duct, variable air volume, central system with return air plenum; fan economizer cycle with enthalpy control; electric centrifugal chiller with cooling tower.	Single duct, constant volume with return air plenum, central system; fan economizer cycle with dry bulb temperature control; electric centrifugal chiller with cooling tower.
Heating System	Electric reheat coils in variable air volume terminal boxes activated at 30% volume for perimeter only. Interior VAV terminal box modulates to total shutoff.	Hot water reheat coils in constant volume terminal boxes, gas-fired boiler.
% Minimum Outside Air	10%	15%
Control System	Pneumatic	Pneumatic
Temperature Control Zones	118	118
Operational Strategy	Night-Lo-Limit, Optimal Start Controllers, Lighting Time Clock Control	Night-Lo-Limit, Lighting Time Clock Control
Other	Elevators, domestic water booster pumps	Elevators, domestic water booster pumps
SYSTEM DESIGN CRITERIA		
Heating/Cooling Loads	800 Tons cooling 470 FT^2/ton cooling 1025 KW Heating	1000 Tons cooling 500 FT^2/ton cooling 1025 KW Heating
Lighting	21.5 W/m^2 (2.0 W/FT^2)	43.0 W/m^2 (4.0 W/FT^2)
Appliance	5.4 W/m^2 (0.5 W/FT^2)	5.4 W/m^2 (0.5 W/FT^2)
Supply Fan Static Pressure	1,492 Pa (6")	1,620 Pa (6-1/2")
Return Fan Static Pressure	248 Pa (1")	248 Pa (1")
Chilled Water Temperatures (EWT/LWT)	7.2°/15.5° (45°/60°)	7.2°/15.5° (45°/60°)
Condenser Water Temperatures (EWT/LWT)	35°/29.4° (95°/85°)	35°/29.4° (95°/85°)
Chilled Water Pump Head	30.5 m (100 FT)	30.5 m (100 FT)
Condenser Water Pump Head	27.4 m (90 FT)	27.4 m (90 FT)

Figure 1. (continued)

ENERGY CONSERVATION MEASURES

OPERATIONAL

A. Energy Audit

1. Conduct energy audit by specialist. Provide owner operating and maintenance manual with description for optimal operation and maintenance procedures.

B. Equipment

1. Shutdown system(s) during unoccupied hours.
2. Revise system(s) operating hours.
3. Revise thermostat settings.
4. Re-establish system(s) balance to original design conditions or match present design loads.
5. Service temperature control systems.
6. Establish routine maintenance of mechanical equipment to insure operation at maximum efficiency.
   a. Improve boiler/chiller operating efficiency incorporating tube cleaning, burner air-fuel adjustment, etc.
   b. Check and tighten belts on belt-drive equipment.
   c. Clean condenser/evaporator cooling coils(s) on refrigeration equipment.
   d. Clean/replace air filters on a regular basis.
7. Adjust outside air damper to minimum position acceptable by Code.
8. Reset heating and chilled water supply temperatures to satisfy revised or actual rebalanced space temperature settings.
9. Reset manually heating and chilled water supply temperatures to match outside temperature conditions.
10. Reduce domestic hot water temperature.
11. Reduce continuous or unnecessary steam boiler blowdown.
12. Repair leaky steam traps.

C. Lighting/Electrical

1. Delamp light fixtures and disconnect ballast.
2. Delamp light fixtures by installing dummy tube.
3. Relamp with lower wattage.
4. Relamp incandescent fixtures with screw-in fluorescents with built-in ballasts as routine O & M procedure for lamp failure.
5. Relamp with high efficiency tubes as routine O & M procedure for lamp failure.
6. Turn off unnecessary lighting.
7. Increase lamp/lens cleaning and maintenance.
8. Reduce parking lot and exterior lighting levels.
9. Disconnect dry transformers when "No Load" condition exists.
10. Use natural daylight to reduce artificial lighting requirements. (Open drapes, blinds, etc.)
11. Reduce internal lighting in refrigeration equipment casings.

D. Miscellaneous

1. Reduce stairwell and corridor heating/cooling temperatures.
2. Reduce operating times for escalators where practical.
3. Turn off office and business machines when not in use.
4. Close draperies or blinds during adverse outdoor conditions.
5. Rearrange desks to avoid draft effect from cold surfaces.
6. Prohibit use of portable electric heaters.
7. Eliminate preheating of ovens and cooking equipment whenever possible.
8. Reduce cooking or process hood supply make-up air system temperature.
9. Change laundry operation to usage of cold water detergent with water setting of 21° (70° F).
10. Reduce/increase spaces(s) temperature setting to satisfy customers' attire; encourage employees/clerks to dress warmer/cooler.
11. Inspect for tight closure of all windows.
12. Turn off refrigeration equipment on drinking fountains.

Figure 2. Candidate energy conservation measures

ENVELOPE

A. Glazing

1. Install reflective solar film. (Assume single glazing as basis. U = 5.67 (1.0), SC = 0.25)

2. Install single tinted glazing. (U summer/winter = 6.24/6.42 (1.10/1.13), SC = 0.69)

3. Install single reflective glazing. (U summer/winter = 6.24/6.42 (1.10/1.13), SC = 0.44)

4. Install double clear glazing. (U summer/winter = 3.17/2.78 (0.56/0.49), SC = 0.82)

5. Install double tinted glazing. (U summer/winter = 3.17/2.78 (0.57/0.49), SC = 0.55)

6. Install double reflective glazing. (U summer/winter = 3.23/2.78 (0.57/0.49), SC = 0.33)

7. Install triple tinted glazing. (U summer/winter = 2.49/2.49 (0.44/0.44), SC = 0.50)

8. Install exterior storm windows.

9. Install interior storm windows.

10. Install exterior shading devices.

    a. Awnings

    b. Sunscreens

    c. Overhangs

    d. Fins

11. Install interior shading devices.

    a. Light-colored, milium-lined drapery

12. Install permanent insulation over glazing.

13. Cover/insulate the upper half of exterior windows.

14. During design phase of new building construction, reduce glazing area.

B. Walls

1. Add insulation by R-1.05 (R-6) increments. (Fiberglass insulation, R=0.21/cm (R=3.1/inch))

    a. R-1.9/8.9 cm (R-11/3½") added total.

    b. R-3.3/15.2 cm (R-19/6") added total.

    c. R-5.3/21.6 cm (R-30/8½") added total.

    d. R-6.7/30.5 cm (R-38/12") added total.

C. Roofs

1. Add insulation by R-1.05 (R-6) increments. (Urethane insulation, R=27.6/m (R=4.0/inch))

    a. R-1.05 (R-6) added total.

    b. R-2.11 (R-12) added total.

    c. R-3.17 (R-18) added total.

    d. R-4.22 (R-24) added total.

    e. R-5.28 (R-30) added total.

    f. R-6.34 (R-36) added total.

2. Apply reflective coating.

3. Add roof water spray or flood system.

4. Provide mechanical ventilation in roof cavity.

D. Floors

1. Add perimeter edge insulation to a 0.61 m (2-foot) underground depth. (Polystyrene, molded bead board, R=0.27/cm (R=4.0/inch))

    a. R-0.70 (R-4) added total.

    b. R-1.4 (R-8) added total.

E. Infiltration

1. Caulk and weatherstrip.

2. Install vapor barriers in perimeter walls and roof structure.

3. Install entry vestibules.

4. Install Door:

    a. Gaskets

    b. Door closer mechanism

    c. Revolving type

    d. Insulated metal core type

5. Install air curtain at entry areas, especially in delivery areas.

6. Rebalance system to insure slightly positive pressure with respect to the outside.

F. Siting

1. Orient building for maximum natural lighting exposure.

2. Orient building to minimize summer solar gain. (Applicable to building types with high glazing wall area ratio.)

3. Orient building to maximize winter solar gain.

4. Use natural vegetation for solar reduction and prevailing wind protection.

5. Incorporate earth berms and sheltering.

Figure 2. (continued)

EQUIPMENT

A. Lighting

1. Install localized task lighting.
2. Re-arrange lighting within space(s) for better quality and location of lighting.
3. Delamp with installation of dummy tubes to avoid.ballast modifications.
4. Install light switching to allow zone control of unoccupied areas.
5. Install/incorporate separate light switching of perimeter areas for maximum benefit of daylight.
6. Replace inefficient lenses with more efficient type, i.e. prismatic plastic and glass for fluorescent applications.
7. Replace ballasts with high power factor units in new and replacement fixture applications.
8. Install photo-electric cells and timer to control outdoor lighting.
9. Rewire parking lot lighting to two levels, one minimum for security, the second for periods of high usage.
10. Reduce after-hour lighting and incorporate use of bypass timers.

B. Electrical

1. Install high efficiency motors.
2. Install two-speed motors--reduces horsepower and airflow on heating/cooling cycle.
3. Install capacitors on motors 10 HP and above to improve building power factor.
4. Install demand limiting sequence controllers.
5. Install computer lighting management system.

C. Temperature Control

1. Add economizer for free cooling with outside air.
   a. Dry bulb control
   b. Enthalpy control
2. Provide night setback control.
3. Provide time clock and bypass timer control.
4. Install optimal start controller for morning start-up.
5. Install dead-band thermostats.
6. Adapt control system to "night flush" or pre-cool structure with cooler nighttime air.
7. Install light sensitive thermostats for temperature setback of unoccupied spaces (lights are turned off; zone air assumes night set back mode.)
8. Add control hardware for reset of chilled/heating water temperatures.
9. Add control hardware for reset of VAV discharge air temperature.
10. Add control hardware for reset of constant volume discharge air temperature.

D. Mechanical Systems

Airside:

1. Convert constant volume systems to variable air volume.
   a. Inlet vanes
   b. Discharge dampers
   c. Scroll dampers
   d. Vaneaxial fan with controllable pitch.
2. Install variable speed fan drives.
   a. Variable sheave
   b. Eddy current clutch
   c. Two-speed motors
   d. Two-motor drive
3. Rezone existing systems(s) as required to satisfy present occupancy usage.
4. Install motorized dampers and fan controls to isolate building areas used for limited periods in 24 hour operational structures.
5. Modify duct systems to reduce internal airflow resistance. Reduce fan horsepower.
6. Install low leakage dampers.
7. Modify and/or eliminate use of conventional sub-cool/reheat systems. Avoid use of multi-zone, induction, terminal reheat and single zone reheat zones.
8. Replace single stage electric duct heaters with multi-stage control.
9. Install hoods over heat-generating equipment--ranges, ovens, process equipments, open tanks, furnaces, etc.
10. Redesign exhaust hoods for reduced exhaust air flow.
11. Provide separate make-up air to areas with high exhaust CFM's. Avoid using central.
12. Replace electric resistance heating systems with heat pumps.

Figure 2. (continued)

Waterside:

1. Reduce by re-balancing chilled and condensing water flow rates. (Becomes feasible when system air side is balanced to actual load conditions correcting oversized systems.)

2. Rebalance hydronic system to reduce internal resistance and pump horsepower.

3. Redesign chiller circuitry for series rather than parallel flow-multiple chiller applications with constant flow.

4. Replace large gas/oil boilers with smaller modular boilers.

5. Equip gas/oil boilers with power burners for step control at part-load conditions.

6. Add flue gas economizers.

7. Provide thermal storage for tank off-peak operation and demand reduction for chilled and heating water systems.

8. Use "strainer cycle" or direct cooling tower precooling in lieu of operating chillers.

9. Trim oversized pump impellers to match required loads.

E. Refrigeration Equipment

1. Increase refrigeration machinery suction temperatures. A 1.6 degree C (3 degrees F) increase can result in 4-1/2 to 6% power consumption reduction.)

2. Reduce condensing temperatures on air cooled equipment by cleaning and rearranging coils for more efficient airflow and adding water spray at coil.

3. Replace air cooled condensers with cooling towers.

F. Plumbing

1. Provide flow controllers in domestic water system fixtures.

2. Incorporate self-closing faucets in public restrooms and other areas where applicable.

3. Recirculate domestic hot water for high usage facilities.

4. Install time clock to control shutdown of domestic hot water recirculation pump(s) during unoccupied hours.

5. Install heat pump water heaters.

6. Install "point of service" electric water heaters.

7. Use separate summer water heater to avoid boiler operation when building does not require heating.

8. Replace gas pilots on water heaters with electric ignition.

9. Install gas water heater flue gas dampers.

10. Insulate hot water heaters.

G. Insulation

1. Insulate domestic water storage tanks, heaters, piping, etc.

2. Insulate hot surfaces passing through conditioned spaces - ducts, pipes, etc.

3. Repair damaged insulation on heating/cooling piping and ductwork.

H. Heat Recovery

1. Incorporate heat recovery from internal zones, computer rooms, exhaust air, condensate, etc.

   a. Heat recovery double-bundled chillers

   b. Templifiers

   c. Laundry heat reclaim systems

   d. Air-to-air heat exchangers

2. Incorporate preheating of combustion air.

RENEWABLES

A. Incorporate passive solar system concepts.

   1. Trombe wall, water wall, etc.

   2. Daylighting

B. Incorporate active heating solar panel concepts.

C. Incorporate active domestic heating water concepts.

D. Install photovoltaic solar cells.

E. Install windmills.

Figure 2. (continued)

ENERGY CONSERVATION MEASURE COSTS

○ CATEGORY CLASSIFICATION: TEMPERATURE CONTROL

- MEASURE

No.	Description
37.	Provide Night Setback Control
38.	Install Optimal Start Controller
39.	Install Dead-band Thermostats

- COSTS:

A. Capital Cost:

	UNIT COST PER TEMPERATURE CONTROL ZONE ($)				
ECM	Material	Labor	Subtotal	O & P	Total
Night Setback Control	30.00	70.00	100.00	15.00	115.00
Optimal Start Controller	250.00	250.00	500.00	75.00	575.00
Dead-band Thermostats	60.00	140.00	200.00	30.00	230.00

B. Maintenance/Operating Cost: None

C. Insurance: 0.3%/year of cost per square foot

Figure 3. Energy conservation measure costing sample

Run #	Total Energy (10^6 Btu)	Peak Demand (kW)	Heat (10^6 Btu)	Cooling (10^6 Btu)	HVAC Aux. (10^6 Btu)	Hot Water (10^6 Btu)	Lights (10^6 Btu)	Vert. Trans. (10^6 Btu)	Misc. (10^6 Btu)	Nonelectric Heat (10^6 Btu)
1	25,032.5	3,053.0	8,085.4	3,557.3	4,705.3	219.7	7,368.4	450.3	645.9	16,947.1
2	24,174.1	2,797.1	7,589.1	3,406.6	4,664.8	49.1	7,368.4	450.3	645.9	16,585.0
	858.4[a]	255.9	496.3	150.7	40.5	170.6	0	0	0	16,535.9
3	22,939.7	2,693.1	7,653.1	3,245.5	4,448.5	49.1	6,441.3	450.3	645.9	15,286.6
	1,234.4	104.0	-64.0	161.1	216.3	0	921.1	0	0	1,298.4
4	22,919.0	2,695.2	7,765.7	3,250.1	4,469.2	49.1	6,288.4	450.3	645.9	15,153.3
	20.7	-2.1	-112.6	-4.6	-20.9	0	158.9	0	0	133.3
5	22,809.0	2,677.2	7,766.3	3,249.9	4,469.2	49.1	6,288.4	340.2	645.9	15,042.7
	110.0	18.0	-0.6	0.2	0.2	0	0	110.1	0	110.6
6	19,883.9	2,194.7	6,952.8	2,343.2	3,264.3	49.1	6,288.4	340.2	645.9	12,931.1
	2,925.1	49.2	813.5	906.7	1,204.9	0	0	0	0	2,111.6
7	19,009.3	2,134.1	6,173.9	2,305.7	3,206.0	49.1	6,288.4	340.2	645.9	12,835.4
	874.6	50.6	778.9	37.5	58.3	0	0	0	0	95.7
8	18,614.9	2,095.8	5,818.4	2,291.2	3,181.7	49.1	6,288.4	340.2	645.9	12,796.5
	394.4	48.3	355.5	14.5	24.3	0	0	0	0	38.9
9	18,176.2	2,055.9	5,440.1	2,289.2	3,123.2	49.1	6,288.4	340.2	645.9	12,736.1
	438.7	39.9	378.3	2.0	58.5	0	0	0	0	60.4
10	14,594.9	1,956.0	2,535.2	1,345.2	3,190.8	49.1	6,288.4	340.2	645.9	11,859.7
	4,220.0	99.9	3,283.2	946.0	-9.1	0	0	0	0	876.4
11	14,108.9	2,036.0	2,177.6	1,385.5	3,222.1	49.0	6,288.4	340.2	645.9	11,931.3
	286.0	-50.0	357.6	-40.3	-31.3	0.1	0	0	0	-71.6

(a) Difference between previous and present cases.

Figure 4. Conservation measure annual energy impacts for new large office in climate zone 1

Run #	ECM Description	Capital (1980 $)	Capital ($/1000 SF)	Energy (kWh/1000 SF)	Demand (Watts/1000 SF)	mills/kWh	$/kW	% Restrictions	kWh/1000 SF	Peak kW/1000 SF
	With Electric Heat									
1	Base Case								23,359	11.60
2	Reduced Outside Air	1,000	2.65	800.9	814.9	0.17	3.3	90	22,557	8.91
3	Relamp	21,250	56.40	1,151.8	331.2	2.50	170.2	75	21,405	8.58
4	Scheduled Lights	10,000	26.54	19.3	0	70.10	∞	30	21,386	8.58
5	Scheduled Escalator	1,000	2.65	102.6	57.3	1.32	46.3	0	21,282	8.53
6	Double Tint to Reflective Windows	64,680	171.66	2,729.4	1,535.0	3.21	111.8	30	18,553	6.96
7	Insulation Wall R-5 to R-11 Roof R-8 to R-19	12,186	36.15	816.1	161.1	12.26	224.3	50	17,737	6.79
8	Insulation Wall R-11 to R-19 Roof R-19 to R-30	13,620	36.15	368.0	153.8	5.01	234.9	30	17,368	6.65
9	Double to Triple Reflective Windows	355,152	942.55	1,592.8	410.2	30.19	2,297.8	0	16,960	6.55
10	Deck-Temperature Reset	50,000	132.70	3,937.0	317.8	1.72	417.5	90	13,432	6.32
11	Optimal Start Control	5,000	13.30	266.7	-159.2	2.50	∞	90	13,165	6.48
	Without Electric Heat									
2X	Reduced Outside Air	1,000	2.56	337.9	814.9	0.40	3.3	90	15,476	8.91
3X	Relamp	21,250	5,640	1,211.6	331.2	2.37	170.2	25	14,264	8.58
4X	Scheduled Lights	10,000	26.54	124.4	0	10.89		50	14,140	8.58
5X	Scheduled Escalator	1,000	2.65	103.2	57.3	1.31	46.3	0	14,037	8.53
6X	Double Tint to Reflective Windows	64,680	171.66	1,970.4	1,535.0	4.41	111.8	30	12,066	6.96
7X	Roof R-8 to R-19	13,620	35.15	56.4	161.1	853.25	224.3	50	11,894	6.79
8X	Insulation Wall R-11 to R-19 Roof R-19 to R-30	13,620	36.15	89.3	153.8	20.65	234.9	30	11,977	6.65
9X	Double to Triple Reflective Windows	355,152	942.55	36.3	410.2	50.81	2,297.8	0	11,941	6.55
10X	Deck-Temperature Reset	50,000	132.70	817.8	317.8	1.72	417.5	90	11,066	6.32

Figure 5. Conservation measure cost effectiveness for new large offices in climate zone 1

Run #	Applicable Square Footage (millions)	Multipliers 1	2	3	Incremental Energy Savings (average MW)	Cumulative Energy Savings (average MW)	Incremental Cost (10^6 1980 $)	Cumulative Costs (10^6 1980 $)	Levelized Cost
2	7.58	1	1.13	1.14	0.71	0.71	0.020	0.020	0.17
2X	8.22	1	0.96	0.74	0.30	1.01	0.022	0.042	0.40
5X	82.16	1	0.96	0.74	0.97	1.98	0.218	0.260	1.31
5	75.84	1	1.13	1.14	0.90	2.88	0.201	0.461	1.32
10	7.58	1	1.13	1.14	3.47	6.35	1.006	1.467	1.72
10X	8.22	1	0.96	0.74	0.77	7.12	1.091	2.558	1.72
3X	61.62	1	0.96	0.74	8.53	15.65	3.475	6.033	2.37
3	56.88	1	1.13	1.14	7.62	23.27	3.208	9.241	2.50
11	7.58	1	1.13	1.14	0.24	23.51	0.101	9.342	2.50
6	53.09	1	1.13	1.14	16.85	40.36	9.113	18.455	3.21
6X	57.51	1	0.96	0.74	12.94	53.30	9.873	28.328	4.44
8	53.09	1	1.13	1.14	2.27	55.57	1.919	30.247	5.01
4X	16.43	1	0.96	0.74	0.23	55.80	0.436	30.683	10.89
7	37.92	1	1.13	1.14	3.60	59.40	1.371	32.054	12.26
8X	57.51	1	0.96	0.74	0.59	59.99	2.079	34.133	20.65
9	75.84	1	1.13	1.14	14.05	74.04	71.483	105.616	30.19
9X	82.16	1	0.96	0.74	0.34	74.38	77.440	183.056	50.81
4	15.17	1	1.13	1.14	0.03	74.41	0.403	183.459	70.10
7X	41.08	1	0.96	0.74	0.26	74.67	1.485	184.944	853.25

Figure 6. Electrical conservation resource potential in new large offices

AVERAGE MEGAWATTS FOR 1980 STOCK OF BUILDINGS

Building Type	Mills/kWh 1	2	3	4	5	10	15	20	25	30	40	50	60	80	100	150
Large Office	46	46	46	49	49	113	125	150	150	150	150	150	150	150	150	150
Small Office	32	44	51	51	51	51	52	52	52	55	55	56	56	56	57	59
Hotel	13	13	14	14	15	15	16	16	19	20	21	21	22	22	22	22
Motel	5	5	6	7	9	11	11	11	12	12	12	12	12	12	12	12
Retail	54	178	178	214	214	226	237	237	237	249	249	249	249	251	253	253
TOTAL	150	286	295	335	352	416	441	466	470	486	487	488	489	491	494	496

AVERAGE MEGAWATTS FOR BUILDINGS CONSTRUCTED 1980 - 2000

Building Type	Mills/kWh 1	2	3	4	5	10	15	20	25	30	40	50	60	80	100	150
Large Office	1	7	24	40	53	56	59	59	60	60	74	74	74	74	74	74
Small Office	10	16	17	17	17	20	20	24	28	28	28	28	28	29	29	29
Hotel	5	7	7	12	13	13	13	15	15	15	15	19	20	20	20	22
Motel	0	23	23	25	26	29	30	30	31	31	31	31	32	32	32	32
Retail	52	52	52	56	65	65	65	65	55	65	65	65	65	65	65	65
School	0	0	4	6	8	8	10	10	12	12	12	12	12	12	12	13
TOTAL	68	105	127	156	182	191	197	203	211	211	225	229	231	232	232	235

Figure 7. Conservation supply function for commercial buildings

Discussion

L.J. Daughtry, Mississippi Power Co., Gulfport: You have identified that the greatest potential for energy conservation in the commercial sector is with the retail customer and office buildings. What programs on energy conservation have you identified to accomplish conservation in these classes of customers?

C.S. Rauch: The focus of this study was not to formulate and administer programs for energy conservation, instead its primary intent was to determine at what cost (mils/kwh), priority and magnitude respective energy conservation measures would occur for commercial buildings. Thus we cannot specifically answer your question directly, as the Power Planning Council is presently formulating the region's policies and programs. It is anticipated, however, a partial to full subsidy or tax credit program, coupled with increased efforts in public education, would be implemented.